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THESIS

A PROPOSAL FOR A COMPUTER NETWORK
FOR THE INDONESIAN AIR FORCE'S
REMOTE SITE RADAR SYSTEM

by

Parulian Simamora

March 1989

Thesis Advisor: G. M. Lundy

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This thesis proposes two alternatives for a preliminary design of a computer network to support this need. It suggests how existing communication resources such as telephones, microwave links and satellite systems can be used to support the network.

The first design, called terrestrial Microwave Radar Data Link, is based on a terrestrial microwave relay. The alternative design, called Fully Connected Satellite Radar Data Link, is based on a satellite microwave relay. Both designs are analyzed as to their security, reliability and economic impact.

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A Proposal for a Computer Network for the Indonesian Air Force's Remote Site Radar System

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The Remote Site Radar System used by the Indonesian Air Force presently uses voice as its sole means of communication. A data communication network which will help store, manipulate and share data in an effective and efficient manner is needed.

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I. INTRODUCTION

The purpose of this thesis is to do a preliminary design of a computer network to support communication between the Indonesian Air Force's Remote Site Radars (RSRs). These new stand alone ground based radar systems are computerized and use Very High Frequency (VHF) and Ultra High Frequency (UHF) transceivers for ground-to-air communication, High Frequency (HF) for ground-to-ground communication, and modem and bus systems for internal communication.

Indonesia has communication system resources such as telephone, radio-link, microwave-link and satellite systems. The goal of this thesis is to suggest how to utilize or implement these resources to support communication between RSRs. The study includes the components and preliminary design of a computer network. No part of the organization is examined.

A. BACKGROUND INFORMATION

Indonesia consists of approximately 13,000 islands which are widely dispersed geographically. The RSRs are located on the four main islands of Java, Sumatra, Borneo and Natuna (See Figure 1). Dispersing the radars geographically offers the following benefits:

1) Reliability - If one radar fails, the others still function properly.

Figure 1. The Locations of the Remote Site Radars [Ref. 1]

2) Security - By dispersing the radar sites, better coverage of the Indonesian air territory is realized.

3) Mobility - Some of the radars are fixed and others are mobile. The mobile radars can be moved from one island to another as the need arises.

The Indonesian Air Force has both defensive and offensive missions. The defensive mission is to protect the country from unknown objects, missiles and hostile aircraft trying to enter the Indonesian territory from the air. The offensive mission is to attack hostile targets.

The goals associated with the defensive mission are to detect the unknown objects, missiles and hostile aircraft 1) on the ground of the hostile country, 2) during transit from the hostile country to Indonesian air territory, and 3) after entering the Indonesian air territory.

In this thesis, a site radar is treated as a network module or node. The internal structure of the system is not discussed.

B. THE EXISTING SYSTEM

The Indonesian Air Force uses the radar system to 1) scan the Indonesian air territory for unknown objects, missiles and hostile aircraft, 2) to guide friendly aircraft or missiles to a target, and 3) to guide friendly aircraft back to homebase after a mission is completed.

Each of the radar sites in the system is a Thomson Radar Model TRC-382C/383. HF transceivers are used for communication between the radar sites (See Table 1). Currently, communication is accomplished by voice only. For ground-to-air communication the radar system uses VHF and UHF. Internal communication within a particular site uses bus systems and modems. The bus systems are used for data communication between the antenna, transmitter and receiver/processing (R/P) cabin. They are similar to MxDx (multiplex demultiplex) and contain two cables. Each cable contains two lines: data line (LD) and procedure line (LP). The procedure line is used to send commands to all devices which are using bus systems. These commands are generated by a bus control unit (BCU). The LP line is used to send and receive the data from one device to and from another device according to the command or program from the BCU. Each equipment in the bus system uses two interfaces, one for interfacing the equipment and the other for interfacing to its bus system (See Figure 2). In this figure, equipment can be a pilot, an antenna, a Secondary Surveillance Radar (SSR), a data processing system, management system, etc.

For communication between the R/P cabin and the Operation cabin, in which the distance is 500 m, modems and Modulation Demodulation Distribution Video (MDDV) are used. The modems used are TRADAN-1420 (4800 bps) and TRADAN-1200 (2400 bps). The TRADAN-1420 modems are used for communication between the computer and management in the R/P cabin (See Figure 3).

TABLE 1. THE EXISTING COMMUNICATION SYSTEM

Mode of Communication	Devices	Frequencies	Descriptions
Ground-to-ground (or Point-to-point) Communication	HF-Tranceiver (Model TRC-382C/383)	2-30 Mhz (SSB)	Use Voice or Continuous Wave 2 sets per site
Ground-to-air (Site-to-aircraft) Communication	VHF Tranceiver and	118-144 Mhz	Use Voice Only 4 Transmitters and 4 Receivers (1 Multi-Freq. and 3 Fixed-Freq.)
	UHF Tranceiver	225-400 Mhz	4 Transmitters and 4 Receivers (1 Multi-Freq. and 3 Fixed-Freq.)
Cabin-to-cabin (or internal) Communication	Bus System	--	There are two cables and each cable contains: - Procedure Line (LP) - Data Line (LD)
	Modem	--	TRADAN-1420: 4800 bps TRADAN-1200: 2400 bps

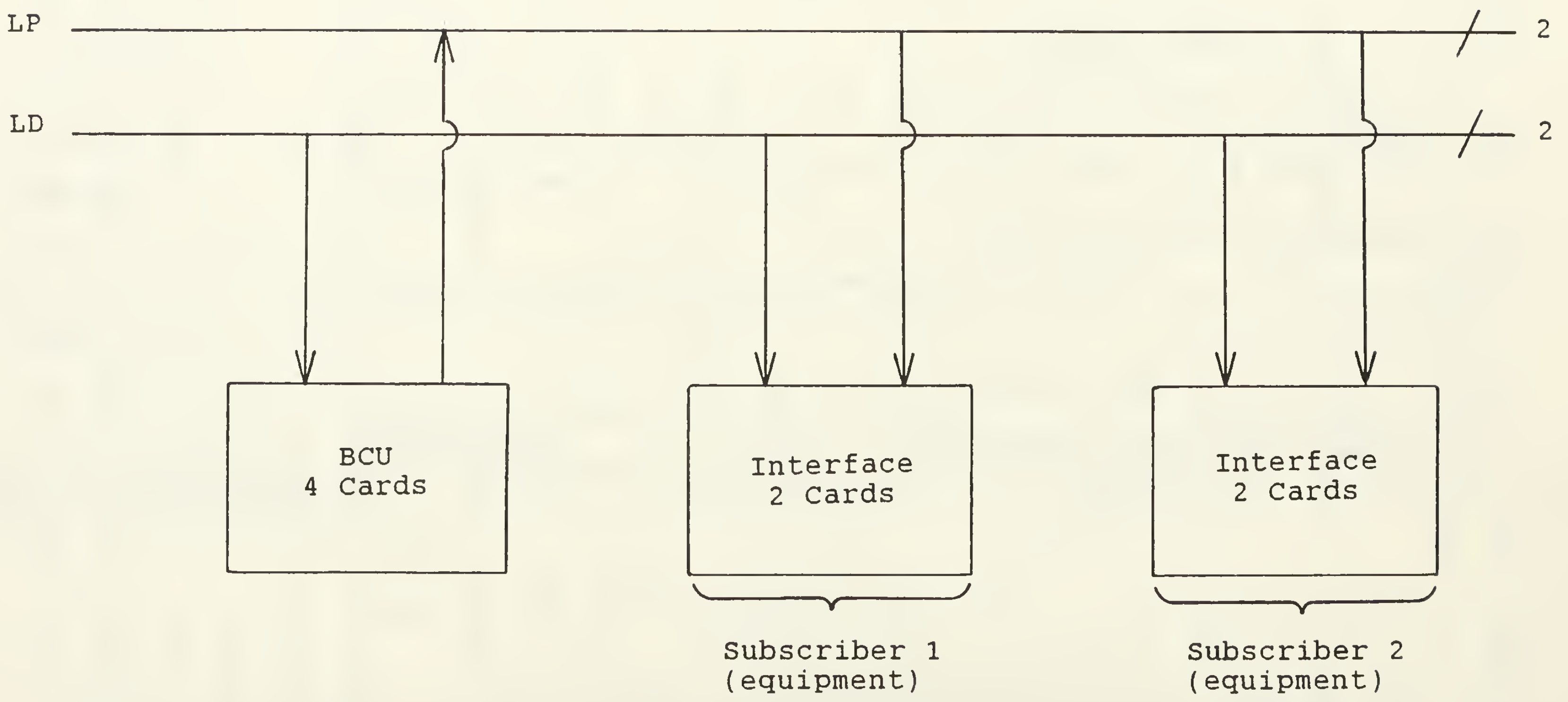

Figure 2. The Bus System

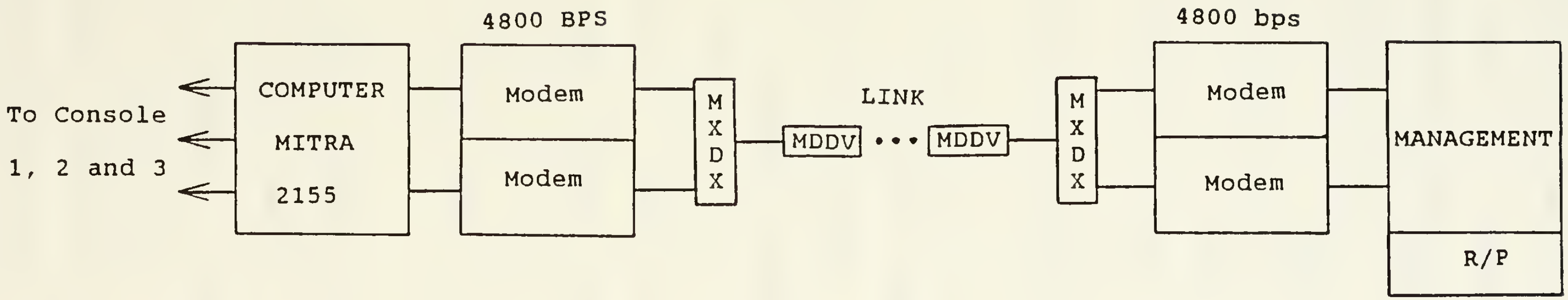

Figure 3. The Communication Between Computer and R/P Cabin

Indonesia has the following satellite communication systems:

1) PALAPA-1: Orbit position longitude is 83 E and frequency band 4 - 6 Ghz.

2) PALAPA-2: Orbit position longitude is 77 E and frequency band 4 - 6 Ghz.

3) PALAPA-B1: Orbit position longitude is 108 E and frequency band 4 - 6 Ghz.

4) PALAPA-B2: Orbit position longitude is 113 E and frequency band 4 - 6 Ghz.

5) PALAPA-Be: Orbit position longitude is 118 E and frequency band 4 - 6 Ghz.

Therefore, for uplink and downlink communication the frequency band must be chosen between 4 - 6 Ghz. These satellites are domestic service satellites and regional coverage systems. The design lifetime of these satellites system is between eight to ten years. For satellite communication systems, we have to consider the cost of communication such as space station cost and earth station cost. On orbit cost is about $40 million or less and the annual cost per circuit is about $80 or less. [Refs. 2 and 3].

In Chapter 2 the present remote site radar communication system, the need for a new system, design goals and the scope of the design are discussed. Chapter 3 discusses design requirements and design constraints. Chapter 4 discusses terrestrial and satellite microwave relays. These are the primary links used in the proposed communication network. Two possible designs are presented; one uses a combination of the two types of links, and the other is based entirely on a satellite link. In Chapter 5, Design 1 and Design 2 are analyzed based on the capacity, security, reliability and cost of the communication links.

II. PROBLEM DEFINITION

A. THE PRESENT REMOTE SITE RADAR COMMUNICATION SYSTEM

The RSR system can detect, identify and give the position, altitude, range and azimuth of the target. This data (or target data) is in analog signal form.

There is presently no data exchange between the RSRs. Outer nodes (sites) report their data to the Sector Operation Center (SOC) by voice only. This type of communication is not secure, effective and efficient if we consider the time, distance, security, human errors and a wartime situation. For efficiency of data transmission (especially over long distances) the target data should be converted into digital signals. Digital signals can be easily transmitted, stored, manipulated and converted back into analog signals. Digital transmission is also more reliable than analog transmission.

B. THE NEED FOR A NEW SYSTEM

The Indonesian Air Force already has experience in implementing and using radar systems from different vendors (or different countries). This past experience (especially in radar communication systems) can be used to help with the design of the new radar communication system. We can learn from past experience and avoid previous mistakes.

1. Need to Get the Data from the Outer Nodes to SOC in a Timely Manner

There is a need for SOC to monitor every site and to send back command and control. To fulfill these needs, each site must be able to send their data to SOC and SOC must be able to send command and control information back via the available communication link as fast as possible. This requirement is very important especially in a wartime situation.

2. Reliability

Some of the radar systems have been operating for four years, some less. The exact failure rate of the systems is not known. But on the average, the failure rate of the components of the communication system in recent years has been unacceptable.

3. Security

The present voice communication system is not secure, especially in a wartime situation. In military operations data can be classified and unclassified. Classified data must be sent through highly secure communication systems in order to be protected from intruders and disasters.

C. DESIGN GOALS

The primary goals for the new system are high reliability and high security.

By interconnecting these radar systems, we can get several advantages, such as:

1) If one site fails, the other sites can perform part of all of its mission.

2) If one communication link fails, the other communication links can be used for data exchange.

The new communication system should be able to use the existing communication capabilities such as satellite-link, radio-link, microwave-link and telephone system. The reliability of the system depends on the software and hardware used in the system and also on the system architecture.

In order to be able to send data from outer nodes to SOC securely, the data must be encrypted. Encryption will allow data to be sent from source to destination without being corrupted. Without security, this communication system is useless.

D. SCOPE OF THE DESIGN

The objectives of this study are:

1) To establish a communication network between RSRs by using the existing resources of communication system.

2) Integration of the RSRs into a unified system.

III. DESIGN BACKGROUND

A. DESIGN REQUIREMENTS

There is a need to use the existing communication system, such as telephone-line, microwave-link, radio-link and satellite-link. The Terrestrial Microwave Radar Data Link design uses a terrestrial microwave relay together with a satellite microwave relay. The Fully Connected Satellite Radar Data Link uses a satellite microwave relay. Terrestrial-link, telephone and radio-link are used as a backup system.

Security is very important in the computer field and military operations. It can be divided into three categories:

1) External security - The computer system must be protected from intruders and disasters, such as fire, floods.

2) Internal security - The hardware and operating system must be protected and secure to ensure the integrity of data and uncorrupted operation of the computer system.

3) User interface security - A user must be identified before accessing the computer system by using a password, voice recognition, finger print, dialog system or other means.

The computer system must ensure that classified data can be read only by a person who has the clearances and authorization to read it. Data must be secured and protected from military espionage, such as wiretapping or eavesdropping. For the RSR network system, there is a need to protect data that is sent from outer nodes to SOC, from SOC to outer nodes, and from node to node. This protection can be done by using end-to-end data encryption and other methods of cryptography. [Refs. 5 and 6].

Reliability is the probability that a system remains operational for a certain time interval. The availability is the expected fraction of time in which the system is available to the users.

The availability of a system can be calculated by using the following formula [Ref. 7]:

$$A = \frac{MTBF}{MTBF + MTTR} \tag{1}$$

where,

- A is the expected fraction of time in which the system is available to users.
- MTBF (Mean Time Between Failures) is the average fraction of time in which the system continues to function without a failure.
- MTTR (Mean Time To Repairs) is the average fraction of time needed to repair the system.

Reliability depends on the hardware and software used in the system. Different vendors produce different devices and these devices also have different reliabilities. It is difficult to determine whether one device is more reliable than other devices before it is put into operation.

For the RSR network system, there is a need to use a highly reliable communication system. If one link fails, the other links should function properly and an alternate route should be available.

Reliability can be improved by the following:

1) Modularity of design - Failures in software and hardware must be easily identified, isolated and corrected.

2) Backup system - The system should provide a good backup system, such as a standby generator with a voltage stabilizer (in case of power failure) and alternative communication systems (in case of one communication system fails).

3) Duplication of components - If one component fails, a standby component should be ready to continue the function.

4) Regular preventive maintenance - By doing regular preventive maintenance, the life cycle of a component can be increased and failures can be reduced.

5) Simplicity of design - Simplicity of design makes the system easier to maintain, the failures easier to find and failures easier to recover from.

There is a need for the SOC to use a Database Management System (DBMS)to organize, store, delete, update, manipulate and retrieve information quickly and efficiently. It should provide the following capabilities:

1) Data integrity - data should be consistent and a backup copy should be produced.

2) Speed - users should get a quick response time.

3) Security - access should be limited to authorized users only.

4) Reliability - the reliability of the individual components of the DBMS should be very high.

5) Accessibility - the DBMS should have a user friendly interface.

6) Efficient use of resources.

7) Compatibility - the DBMS should be easy to interface to the existing hardware and software system [Ref. 8].

B. DESIGN CONSTRAINTS

The primary design constraints in this network are distance and cost. Due to the time-distance relationship, the sites which are farther apart need more time to interact with each other. Therefore, distance affects the choice of communication links. For long distance communication terrestrial microwave, satellite microwave or a combination of these would be the medium of choice.

Geographical distance also affects the operational costs of the site. As the distance between sites increases the cost of transporting parts, supplies, personnel and other needed items also increases.

As the system is dispersed geographically and the distances increase, the security of the system becomes more difficult to control [Ref. 9].

IV. PROPOSED DESIGNS

A. INTRODUCTION

In this chapter, general information and two proposed designs will be discussed. Each design will be analyzed according to the design goals and design requirements. Their strengths and weaknesses are also discussed.

1. The Locations of the RSRs

In the RSR network, there are seven radar sites which need to be interconnected by using the existing communication system (See Figure 1). The names of the RSRs are: Sector Operation Center (SOC), Tanjung Kait (TKT), Pakanbaru (PKB), Lhokseumawe (LSW), Ranai (RNI), Balikpapan (BPP) and Madiun (MDN). In this radar system, the SOC is the central site. The distance between each site radar pair can be seen in Table 2.

The SOC is located at Jakarta (the capital city of the Republic of Indonesia) on Java Island. The TKT and MDN site radars are located on Java at the small towns of Tanjung Kait and Madiun, respectively. The PKB site located at Pakanbaru and the LSW site at Lhokseumawe are on Sumatra Island. The RNI site is on Natuna Island at a town named Ranai. The final site, BPP is on Borneo at the town of Balikpapan (See Figure 1).

TABLE 2. THE STRAIGHT LINE DISTANCE BETWEEN SITE RADARS (IN KM)

TO / FROM	SOC	TKT	PKB	LSW	RNI	BPP	MDN
SOC	--	50	1030	1640	1130	1220	550
TKT	50	--	950	1560	1100	1290	600
PKB	1030	950	--	590	860	1700	1480
LSW	1640	1560	590	--	1260	2265	2100
RNI	1130	1100	860	1260	--	1100	1300
BPP	1220	1290	1700	2265	1100	--	900
MDN	550	600	1480	2100	1300	900	--

There are several functions of the SOC:

1) To monitor the other sites.

2) To get the data from each site and process the data.

3) To give command and control to every site.

4) To manage the operation of the network.

In considering the distance between nodes, reliability, security, the existing communication system and cost of communication system, it becomes clear that there is a need to use terrestrial and satellite links. This is due in part, to the geography and great distances involved. Much of the distance is across bodies of water such as the Java Sea, Strait of Sumatra and South China Sea.

In recent years, the cost of computer hardware has continued to decrease. This has the affect of reducing the cost of the communication system. As the security of the nation becomes a greater priority, the cost of communication link becomes a less important consideration (especially in a wartime situation).

2. Centralized and Distributed Solutions

In a distributed processing system, we need to use a communication network in order to coordinate all of the activities of the standalone processors/computers and to exchange data between them. The system should be flexible so that advances in technology can be incorporated and it should fulfill users needs.

a. Hardware

Each node of a distributed system has its own local processor (computer) and memory. As the cost of computer hardware continues to decrease, this impact will reduce the cost of the communication system. As the cost of the communication systems decrease, it may become possible to interconnect the distributed system with effective cost.

b. Control

There is a need to control and manage the hardware and software in a distributed system in order to be able to use it effectively and efficiently. Controls in distributed systems can be local, centralized and hierarchical.

c. Data

Data in the system must be controlled. Data can be replicated and put into different locations for redundancy. If one site fails, the other sites still have a copy of the data and can take over the function of the failed system.

On the other hand, a centralized computer system has the following advantages and disadvantages:

<u>Advantages</u>

1) Centralized computer center would have all of the software immediately available thereby simplifying and speeding up accessibility.

2) The operating cost of a centralized computer system is cheaper.

3) Security is simpler since everything is centralized.

Disadvantage

1) The reliability of the centralized network depends on a central switch. If this central switch fails, the operation of the network completely stops. Therefore, the reliability of a centralized network is poor.

A centralized network takes the form of star topology in which there is a link from a central switch to every node. This topology offers good performance because there is no interference between links. If one link fails, then only that link will not be able to communicate with the central switch. In this topology the cost of the link is expensive, because there is no sharing of links. [Ref. 10]

3. Computer and Network Security

The most vulnerable system in the computer network is its communication link. It is useless to protect the computer if the network is vulnerable. This section discusses computer system and network security, such as system threats, control mechanisms and security strategies.

a. Computer System Threats

Threats to the computer system can be active, passive and accidental. Active threats are those in which there is an attempt to purposely change data or penetrate the computer processing system. These threats can be file penetration, program modification, system modification, system subversion, file modification and unauthorized system usage. [Ref. 11]

Passive threats are those in which there is an attempt to just read data or intercept messages. These threats can be leakage (data is transmitted to unauthorized users) and physical exposure of the communication link and terminal to external interception.

Accidental threats can be software, hardware and communication system failures.

b. Security Strategies

There are several strategies for implementing a computer security system, such as isolation, delegation of responsibility and encipherment. Isolation means the computer system is isolated from unauthorized users. Delegation of responsibility is to delegate the responsibility for security of the system to someone such as a security officer. Encipherment is a method of interposing a code between the user and the computer system. In this case, the user must decipher the code before logging on or accessing the system.

c. Control Mechanisms

Control mechanisms can be divided into access control, integrity control and memory control. Access control is a method of preventing an unauthorized user from accessing the system or restricting access to data. Integrity controls are designed to ensure that the system and its data remain uncorrupted. Memory control is a method of preventing an unauthorized user from reading from or writing to memory or system files. [Ref. 12]

4. Terrestrial Microwave Links

Terrestrial microwave data links usually operate on frequencies in the range of 1000 to 8000 Mhz and have data rates from 10 to 100 Mbps. Their propagation delay is about 6 microsecond/Km. Small dish antennas mounted on towers can give very narrow beams for line of sight communication between a transmitter and receiver. Because of narrow beams, low-power transmitters can be used. A transmitter output of 1 Watt gives adequate reception at a distance of 50 miles. If the line of sight between two points is not possible, because of obstacles such as mountains, a repeater can be inserted between transmitter and receiver. A diagram of a microwave radar data link can be seen in Figure 4.

If there are no obstacles along the link, then the distance between two antennas can be calculated by using the following formula [Ref. 13]:

$$D = 7.14\sqrt{Kh} \qquad (2)$$

where,

- D is the distance between the two antennas (Km)
- K is the adjustment factor for curvature of the earth (usually K = 4/3)
- h is the height of the antennas measured from ground level or sea level (m).

Transmission loss also occurs in microwave links. This loss is caused by attenuation. Transmission loss in a

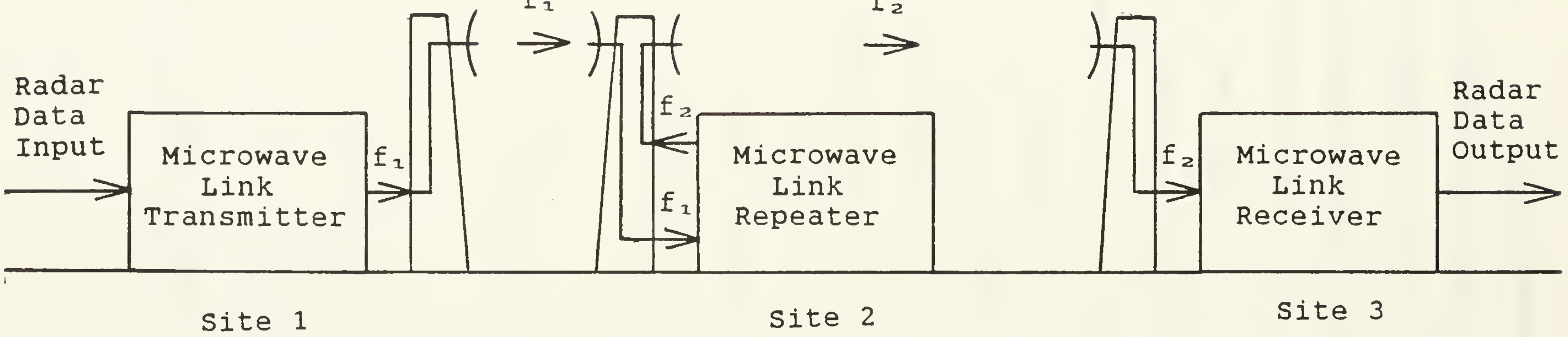

Figure 4. Basic Diagram of Microwave Radar Data Link

microwave link can be calculated by the following formula [Ref. 13]:

$$L = 10 \log(4\pi\frac{D}{\lambda})^2 \tag{3}$$

where,

- L is the transmission loss measured in dB
- D is the distance, and
- λ is the wavelength.

Based on these two formulas, we can analyze and determine the number of repeaters needed and the loss for each link.

a. Characteristics of Transmission Links

(1) Reflection. When the electromagnetic waves strike a smooth, polished surface, they are reflected with an angle of reflection equal to the angle of incidence [Ref. 14].

(2) Refraction. Refraction is the bending of electromagnetic waves as they pass from one medium to another with different refractive indices. The refractive index is defined as the ratio of the velocity of light in a vacuum to the velocity of light for a given transmission medium. Refractive index decreases linearly with height and depends on the atmospheric conditions, such as pressure, temperature and humidity. It may cause the electromagnetic waves to be bent toward the earth or away from the earth.

Electromagnetic waves which are propagated in a more dense transmission medium will travel slower than those travelling in a less dense medium. As a result, the electromagnetic waves follow the curvature of the earth. In standard atmosphere, the parameter K is the adjustment factor for the curvature of the earth. The value of K is 4/3 times the earth's radius. [Ref. 14]

(3) Fading. Fading is the fluctuation in intensity of electromagnetic waves due to changes in parameters of the transmission medium [Ref. 14].

(4) Ducting. Ducting is the trapping of an electromagnetic wave, caused by a layering of the transmission medium in low altitude, high density atmospheric layers. Ducting occurs most frequently over large bodies of water and in an area where temperature inversions often take place. [Ref. 14]

(5) Weather. Weather irregularities also affect the transmission of electromagnetic waves. When a fog front occurs in a microwave link, refraction may result which will increase the link attenuation. Heavy rainfall also increases attenuation. Therefore, when doing link calculations, the rain attenuation should be included especially at frequencies above 10 Ghz. [Ref. 14]

b. Microwave Link Engineering

In this section we will discuss about how to provide the best transmission of data from source to destination over a given link. The first step is to link the sites (nodes) directly and then divide this link by 50 miles. This is done because for line of sight communication, a transmitter output of one watt gives adequate reception at a distance of 50 miles. Dividing the total link distance by 50 miles yields the number of repeaters needed for the link. Next, one must consider the output power of the transmitter, the gain of the antennas both for transmitter and receiver, link loss, connector loss and transmission line loss. [Ref. 14]

(1) Link Selection. The local terrain and characteristics of the area in which the link will be established, such as whether the area is rural or urban must be considered. By putting a repeater station on top of a mountain, hill or building we can reduce the height of the antenna needed. Whenever topographically possible or economically feasible linking over large bodies of water, such as a seas, lakes and rivers should be avoided to reduce the errors caused by transmission reflection from the surface of the water. [Ref. 14]

(2) The Location of the Repeater. The location of the repeater must be chosen carefully by considering the current topographical maps and aeronautical charts. The repeater must be accessible for maintenance and construction.

A survey is needed to check for man-made and other obstacles such as big trees not shown on the map. The elevation of the highest point around the link should be verified. A survey is very important before the actual links are established to avoid unnecessary costs later. After the location of the repeater has been selected, height of the antennas (or towers) must be calculated. [Ref. 14]

(3) The Height of the Antenna. The height of the antenna is calculated by using formula 2.

5. Satellite Microwave Links

This section will focus on communication via satellite microwave relay only. A satellite system can be used as a relay station to link two or more earth stations. If one earth station (source) wants to communicate with another earth station (destination) it transmits the data to the satellite on the uplink frequency. The satellite amplifies the signal if it is analog and repeats it if it is digital. It then retransmits the signal down to the destination (on the downlink frequency). To accomplish this, the satellite system uses a transponder. A transponder will use different frequencies for the uplink and downlink transmissions to prevent interference. [Ref. 15]

The signal quality for uplink communication depends upon the strength of the signal which is sent from the earth station to the satellite and how well the satellite receives it. The signal quality for the downlink communication depends on the strength of the signal sent from the satellite to the earth station and how well the earth station receives it. [Ref. 15]

Therefore, to establish a satellite microwave link we need earth stations and a satellite with a transponder. The satellite must be in a geosynchronous orbit otherwise the line of sight communication between the satellite and the earth stations can not be maintained. The satellite's geosynchronous orbit is about 35,860 Km above the equator.

Usually, the range of frequencies for satellite transmission is between 1 - 10 Ghz at the rate of 10 - 100 Mbps. A transmission below 1 Ghz will be affected by man-made and atmospheric noise. On the other hand, transmissions above 10 Ghz will experience attenuation because of atmospheric absorption and precipitation. Therefore, for transmission via a satellite system, the frequency band must be between 1 - 10 Ghz. [Ref. 16]

There are several other important things that must be considered when using a satellite communication system. First, many earth stations can transmit to and receive information from a satellite. If a secure communication system is desired, end-to-end data encryption or some other method of cryptography must be used to protect the links from intruders. Second, because the distance from the earth station to the satellite is very long, the propagation delay is also very long (between 250 - 300 msec). Third, if the satellite system malfunctions or is shot down by the enemy then communication via a satellite system will fail. Because of this, there is a need to have a backup communication system. Fourth, the Indonesian satellite coverage includes other countries, such as Malaysia, Thailand, Philippines, New Guinea and some parts of Australia. For security reasons, satellite coverage must be focused within the Indonesian territory. [Refs. 15 and 16]

a. **Components of Satellite Communications**

(1) Transponders. The basic functions of a transponder are amplification and frequency translation. A signal received by the receiver antenna of the satellite transponder is amplified and its frequency is translated to another frequency. Then the signal is retransmitted back to earth via the transmitter antenna of the satellite [Ref. 17].

(2) Frequency Bands. There are six frequency bands that have been allocated for satellite communications. Of the six frequency bands, three are for military application and the other three are for commercial use. The three bands for military application are called the Ka, X and UHF bands. The Ka-band uses a frequency range between 20,200 - 21,200 Mhz for downlink transmission and 43,500 - 45,500 Mhz for uplink transmission. The X-band uses a frequency range between 7,250 - 7,750 Mhz for downlink transmission and 7,900 - 8,400 Mhz for uplink transmission. The UHF-band uses a frequency range between 250 - 270 Mhz for downlink

transmission and 292 - 312 Mhz for uplink transmission. [Ref. 17]

(3) Earth Stations. An earth station can communicate directly with a satellite. It may contain several elements, such as an antenna, high-power amplifier, low-noise amplifier, up-converter and down-converter. An earth station antenna can be used for transmitting data to the satellite and receiving data from the satellite. The antenna must have the following attributes: a low-noise temperature, ability to be easily steered, and have a highly directive gain. The most commonly used high-power amplifiers for earth stations are called travelling wave tube amplifier (TWTA)). This TWTA is used to generate the power in the range of Kilowatts. The most widely used low-noise amplifiers for earth stations are Ga As FET and parametric amplifiers. The parametric amplifier can provide very low-noise temperatures. On the other hand, a Ga As FET low-noise amplifier provides stability, reliability and low cost. An up-converter is used to convert the input signal for a given frequency to a higher frequency, without changing the modulation method. A down-converter is used to convert the input signal for a given frequency to a lower frequency. [Ref. 17]

(4) Spacecraft. A spacecraft provides a stable platform on which the satellite control equipment, such as the power system, stabilization, propulsion, attitude

control, telemetry and tracking and command system can function and be maintained. [Ref. 18]

b. The Unique Properties of Satellite Links

There are several unique properties of satellite links that need to be considered before links can be established [Ref. 19]:

1) Broadcast and point-to-point communications are possible via a satellite system.

2) Transmission costs via a satellite system are independent of the distances between the ground stations.

3) There is a propagation delay of about 250 msec.

4) Signals from a satellite system can be received by many earth stations and many earth stations can transmit to the satellite system. These security problems must be considered carefully.

5) The quality of transmission is very high.

6) An earth station can receive its own transmission. Therefore, it knows whether its transmission was successful or whether it resulted in a collision.

7) A satellite system provides very high bandwidths or data rates.

8) It is better to use digital signals for data transmission, because digital signals can be easily transmitted, stored manipulated and converted back into analog signals. Also, a digital signal is more reliable than an analog signal. [Ref. 20]

B. DESIGN 1: MICROWAVE RADAR DATA LINK

Design 1 is illustrated in Figure 5. It has a non fully-connected mesh topology. It uses a combination of terrestrial and satellite microwave transmission media. Today the most common media used for long haul communications

Figure 5. Design 1: Terrestrial Microwave Radar Data Link

are terrestrial microwave relay, satellite relay and fiber optic cable.

1. Terrestrial Microwave Radar Data Link Between SOC and TKT

As illustrated in Figure 5, the straight line distance between the SOC and TKT sites is 50 Km. These two sites are located in an area without mountains or hills. The location of the SOC is in Jakarta which has many tall buildings which are potential obstacles. If there are no obstacles around the link, communication can be established between the two sites. To cover the distance of 50 Km, towers for antennas can be built for both site radars. The necessary height of the tower is calculated by using formula (2) as follows:

$$D = 7.14\sqrt{Kh}$$

$$50 = 7.14\ \sqrt{(4/3)h}$$

$$2500 = 67.9728h$$

$$h = 36.77941765 \text{ meters}$$

If towers are built with heights of about 37 meters, this link can be established without using repeaters.

2. Terrestrial Microwave Radar Data Link Between TKT and PKB

As illustrated in Figure 5, the distance between the TKT and PKB site radars is 950 Km. There are many mountains on the west end of Sumatra. On these mountains, repeaters can be built. The highest mountain near PKB is mount Kerinci

(3800 meters). If a repeater is built on this mountain, the distance:

$$D = 7.14\sqrt{(4/3)3800}$$

$$D = 508.2289248 \text{ Km}$$

can be covered. The distance from PKB to mount Kerinci is 370 Km so this mountain can be used as the repeater location.

A higher mountain also located on the west end of Sumatra is mount Dempo (3159 meters). From this location a distance of:

$$D = 7.14\sqrt{(4/3)3159}$$

$$D = 463.3854499 \text{ Km}$$

can be covered.

The distance from Kerinci to Dempo is 335 Km so repeaters placed on each of these mountains could communicate. The distance from mount Dempo to TKT is 380 Km which can be reached by a repeater on mount Dempo. Therefore, to establish a link between TKT and PKB only two repeaters are needed. One in mount Kerinci and the other on mount Dempo.

3. Terrestrial Microwave Radar Data Link Between PKB and LSW

The distance between the PKB and LSW site radars is 590 Km. The highest mountain for this link is a mountain south of LSW called mount Leuser (3381 meters). From this mountain a distance of:

$$D = 7.14\sqrt{(4/3)3381}$$

$$D = 479.3913191 \text{ Km}$$

can be covered. The distance from LSW to this mountain is 180 Km which is less than 479 Km so this distance can be reached from this mountain. The distance from mount Leuser to PKB is 450 Km so this distance can also be covered from this mountain. If a repeater is built on mount Leuser, a link can be established with one repeater.

4. Satellite Microwave Radar Data Link Between LSW and RNI

The distance between the LSW and RNI site radars is 1260 Km. As the map shows, this link is across the Strait of Sumatra, Malaysia and the South China Sea. If an agreement between Indonesian government and Malaysian government can be established some repeaters could be placed in Malaysia. If no agreement can be reached a link could be established between the two sites by using a satellite microwave system. Signals coming from the satellite could be transmitted to the other sites via terrestrial microwave links. Ground stations at LSW and RNI would be required.

Considering the distance, security and cost of communication on this link, it would be better to use a satellite microwave link for this network. For security of the satellite link, end-to-end data encryption or some other method of cryptography could be used.

5. Satellite Microwave Radar Data Link Between PKB and RNI

The distance between the PKB and RNI site radars is 800 Km. This link would also cross the Strait of Sumatra, Malaysia and the South China Sea. This link could be established in the same way as the LSW and RNI link.

6. Terrestrial Microwave Radar Data Link Between SOC and MDN

Figure 5 shows that the distance between the SOC and MDN site radars is 550 Km. There are many mountains between these locations. The highest mountain is mount Slamet (3428 meters) which is in the middle of the path. From this mountain the distance:

$$D = 7.14\sqrt{(4/3)3428}$$

$$D = 482.7118793 \text{ Km}$$

can be covered. The distance from SOC to mount Slamet is 290 Km and the distance from mount Slamet to MDN is 350 Km. The two distances can be covered by using one repeater on this mountain.

7. Terrestrial Microwave Radar Data Link Between MDN and BPP

The distance between the MDN and BPP site radars is 900 Km. This link would cross the Java Sea. MDN is located on Java Island and BPP is on Borneo Island. West of MDN, is mount Semeru (3676) meters). If a repeater is built on this mountain, a distance of:

$$D = 7.14\sqrt{(4/3)3676}$$

$$D = 499.8679954 \text{ Km}$$

can be covered. The distance from MDN to this mountain is 150 Km which is much less than 499 Km. From mount Semeru a small town called Pelaihari on Borneo Island can be reached and so a repeater could be built in this town. Another mountain to the south of BPP is mount Besar (1892 meters). From this mountain the distance of:

$$D = 7.14\sqrt{(4/3)1892}$$

$$D = 358.6147482 \text{ Km}$$

can be covered. The distance from Pelaihari to this mountain is 160 Km and from this mountain to BPP is 215 Km. These two distances can be covered from mount Besar. Thus, to establish a link between MDN and BPP three repeaters are needed, one on mount Semeru, one in the town of Pelaihari, and the other on mount Besar.

8. Satellite Microwave Radar Data Link Between BPP and RNI

The distance between the BPP and RNI site radars is 1100 Km. This link must cross Malaysia and the South China Sea. This is a similar situation to the LSW and RNI link so the same solution would apply.

9. Satellite Microwave Radar Data Link Between SOC and RNI

It is very important to link SOC directly to RNI since the role of the RNI is as an early warning system. The distance between these two site radars is 1130 Km. This link is directly across the Java Sea. Due to the curvature of the earth, direct transmission is impossible. The cost of building repeaters on the sea or of using undersea cable for this link is very high. So it would be better to use a satellite microwave link with end-to-end data encryption for security.

C. DESIGN 2: FULLY CONNECTED SATELLITE RADAR DATA LINK

Design 2 is illustrated in Figure 6 which is a fully connected satellite link. This design is based entirely on satellite links. An important consideration when using a satellite relay is the amount of propagation delay. Since the round trip distance that a signal must travel from one ground station up to the satellite and back down to the second ground station is about 75,000 Km and the speed of transmission is equal to speed of light (300,000 Km/sec) we get a propagation delay of 250 to 300 msec. Satellite propagation delays are significantly greater than terrestrial microwave propagation delays (which are about 6 microsecond/Km). This delay depends not only on the distance, but also on the bandwidth and error rates of the system.

If two satellite systems are close enough together, interference may occur. To prevent this interference, a spacing of 4 degrees is required with a frequency band of 4/6 Ghz. Interference may also occur if the frequencies for the

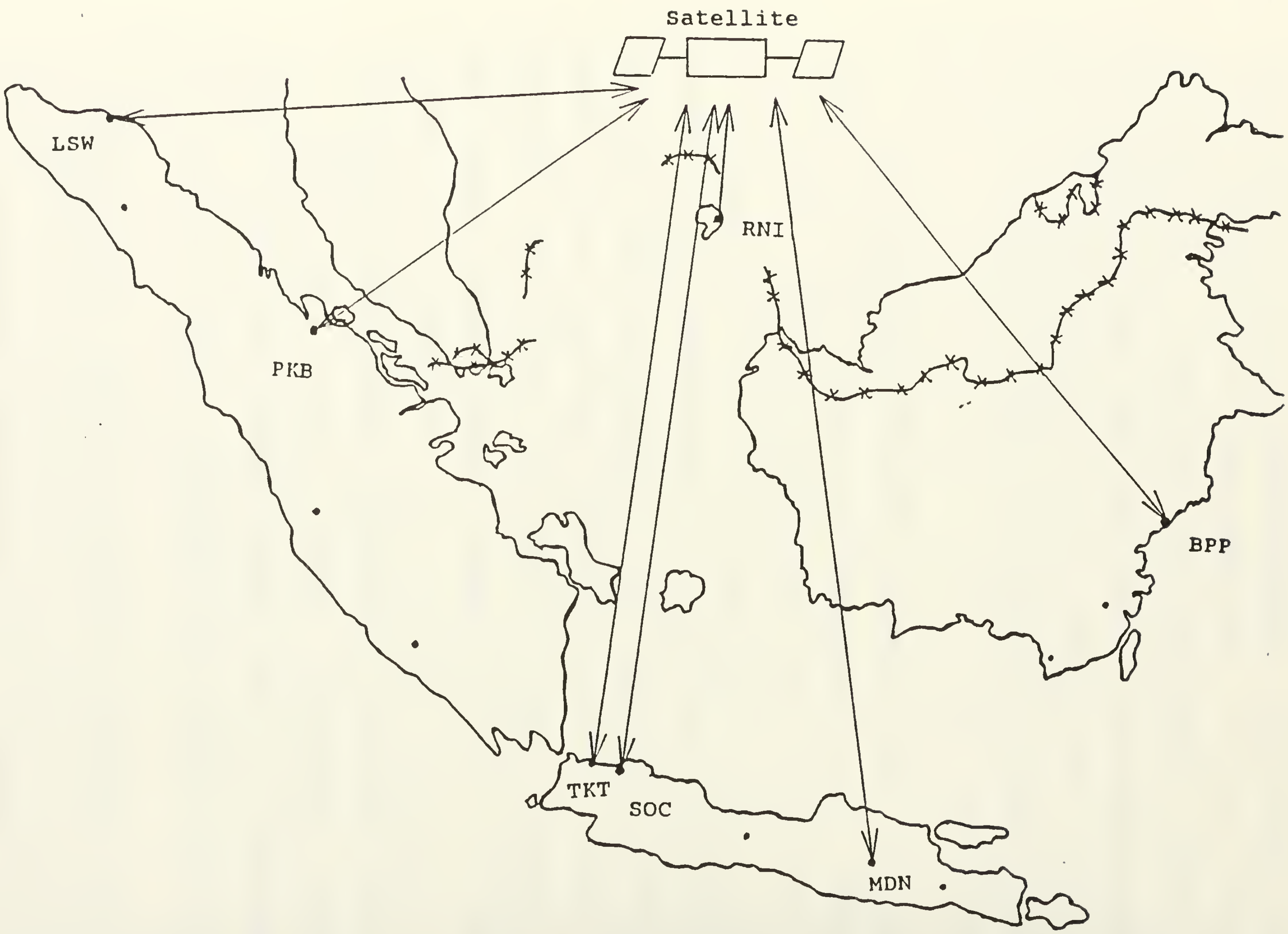

Figure 6. Design 2: Fully Connected Satellite Radar Data Link

uplink and downlink transmissions are the same. To prevent this interference, the frequency for uplink and downlink transmission must be separated.

One of the objectives of this design is to use the existing communication system such as the satellite system currently in use. This satellite system has both 4 and 6 Ghz frequency bands. Therefore, for a satellite microwave radar data link the frequency band chosen must be compatible with these values. For a frequency band of 4/6 Ghz, most satellite systems use a frequency range of 5.925 - 6.425 Ghz for uplink transmission and a frequency range of 3.70 - 4.20 Ghz for downlink transmission. For the 4 Ghz frequency band the maximum channel bandwidth is 20 Mhz. At this bandwidth, the data rate is between 12 - 90 Mbps. For the 6 Ghz frequency band the maximum channel bandwidth is 30 Mhz, giving a data rate of 90 Mbps. [Refs. 19 and 21]

1. Characteristics of Satellite Links

a. Types of Earth Stations

The types of earth stations for satellite links can be fixed-assignment carrier, multiplexed or user stations. With fixed-assignment carrier, a satellite link is used for long-distance transmission and to carry a bulk of data. The carrier can be frequency division multiplexed (FDM) or time division multiplexed (TDM). A multiplexed earth station has several user stations attached. The user stations can not communicate directly with satellite but rather must communicate via the earth station. The earth station multiplexes the incoming traffic from its attached user stations. [Ref. 13]

b. **Satellite Link Configuration**

Satellite link can be used for point-to-point, point-to-multipoint, multipoint-to-point and multipoint-to-multipoint communication. Point-to-point link is a method of communication in which two sites can communicate directly. Point-to-multipoint (broadcast) link is a method of communication in which one site can communicate with multiple sites. Multipoint-to-point (data gathering) link is a method of communication in which multiple sites can communicate to one site. Multipoint-to-multipoint (multiple access) link is a method of communication in which multiple sites can communicate with multiple sites. [Ref. 13]

c. **Channel Allocation**

Channel bandwidth in a satellite link needs to be allocated effectively and efficiently. For example, a satellite system with a 500 Mhz bandwidth can be broken up into twelve 40 Mhz channels of smaller bandwidth. From this 40 Mhz channel, 4 Mhz is used for guard bands which are used to separate the channels in order to prevent interference. Therefore, each channel is actually 36 Mhz. For each of these channels there is a need to allocate their capacity. Channel capacity is the maximum amount of information that can be sent through a given channel. [Ref. 13]

Channel allocation strategy can be FDM or TDM. With FDM, the frequency band is divided into several smaller channels. If multiple sites are sharing the smaller channels, this method is called frequency division multiple access (FDMA). With TDM, the frequency band is divided into time slots. Allocation of a time slot can be fixed, dynamic or a combination of these.

2. Multiple Access Techniques

a. Time Division Multiple Access (TDMA)

With TDMA, multiple earth stations share a single satellite transponder channel (See Figure 7). All earth stations are allowed to transmit their bursts in a given time frame (TDMA frame). Their bursts arrive at the transponder at different times without overlap because there are small time gaps (guard times) between them. These time gaps are used to prevent interference between bursts. TDMA will function properly if all the signals transmitted on the downlink can be received by all the earth stations. On the other hand, this method is not efficient because transmitting all signals to all earth stations wastes the power of the satellite and uses up the entire frequency band. [Ref. 12]

b. Satellite Switched Time Division Multiple Access (SS-TDMA)

SS-TDMA is a multiple access protocol used to overcome the problems associated with TDMA. Advanced TDMA satellite antennas can focus all their energy toward a single earth station. Multiple spot beams can be generated by a

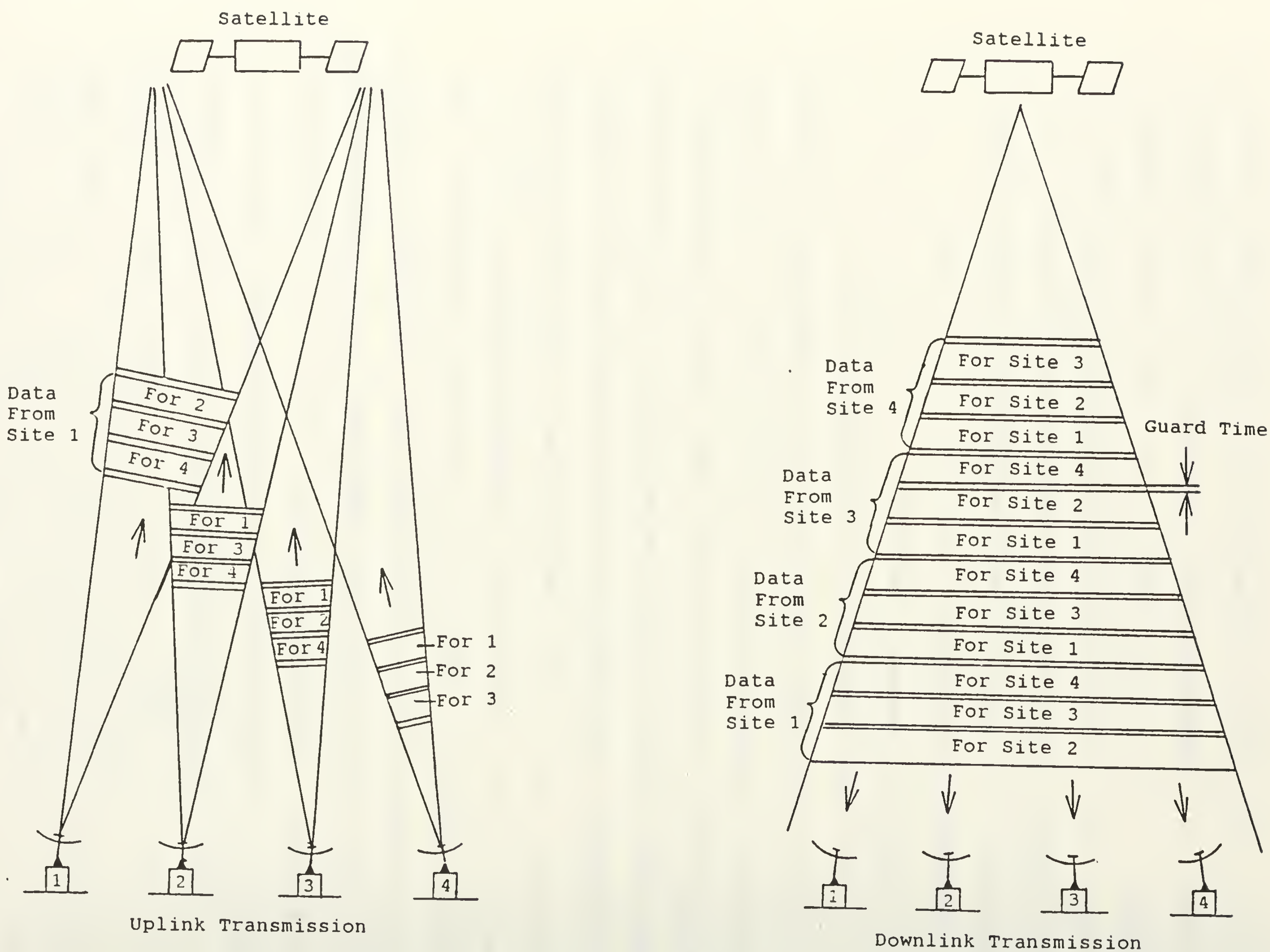

Figure 7. Time Division Multiple Access

single antenna with enough separation between beams to allow the same frequency band to be reused many times. This technique is very efficient because it uses all the available frequency band and is used for high-traffic links. SS-TDMA uses a switching technique to dynamically change the channel allocation. For a point-to-point link, there are separate beams from the satellite for the various receiving stations (See Figure 8). [Ref. 22]

c. **SS-TDMA Area-Coverage Beams**

SS-TDMA Area-Coverage Beams is a modification of the SS-TDMA protocol. The operation of this technique is very similar to the TDMA operation in which multiple earth stations share a single satellite transponder channel. Therefore, the station operation is intermittent because like TDMA transmissions occur in bursts (See Figure 9). [Ref. 22].

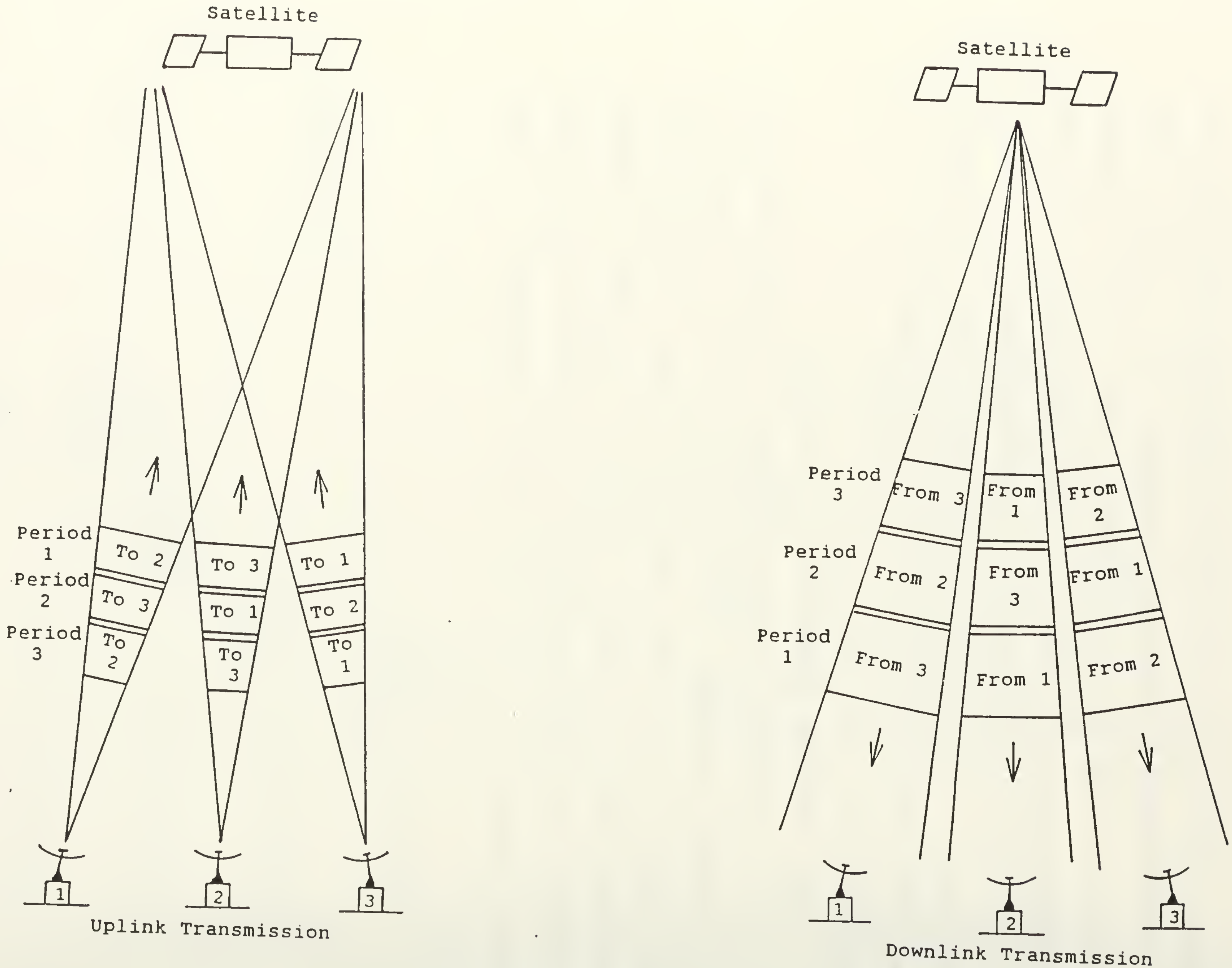

Figure 8. Satellite Switched Time Division Multiple Access

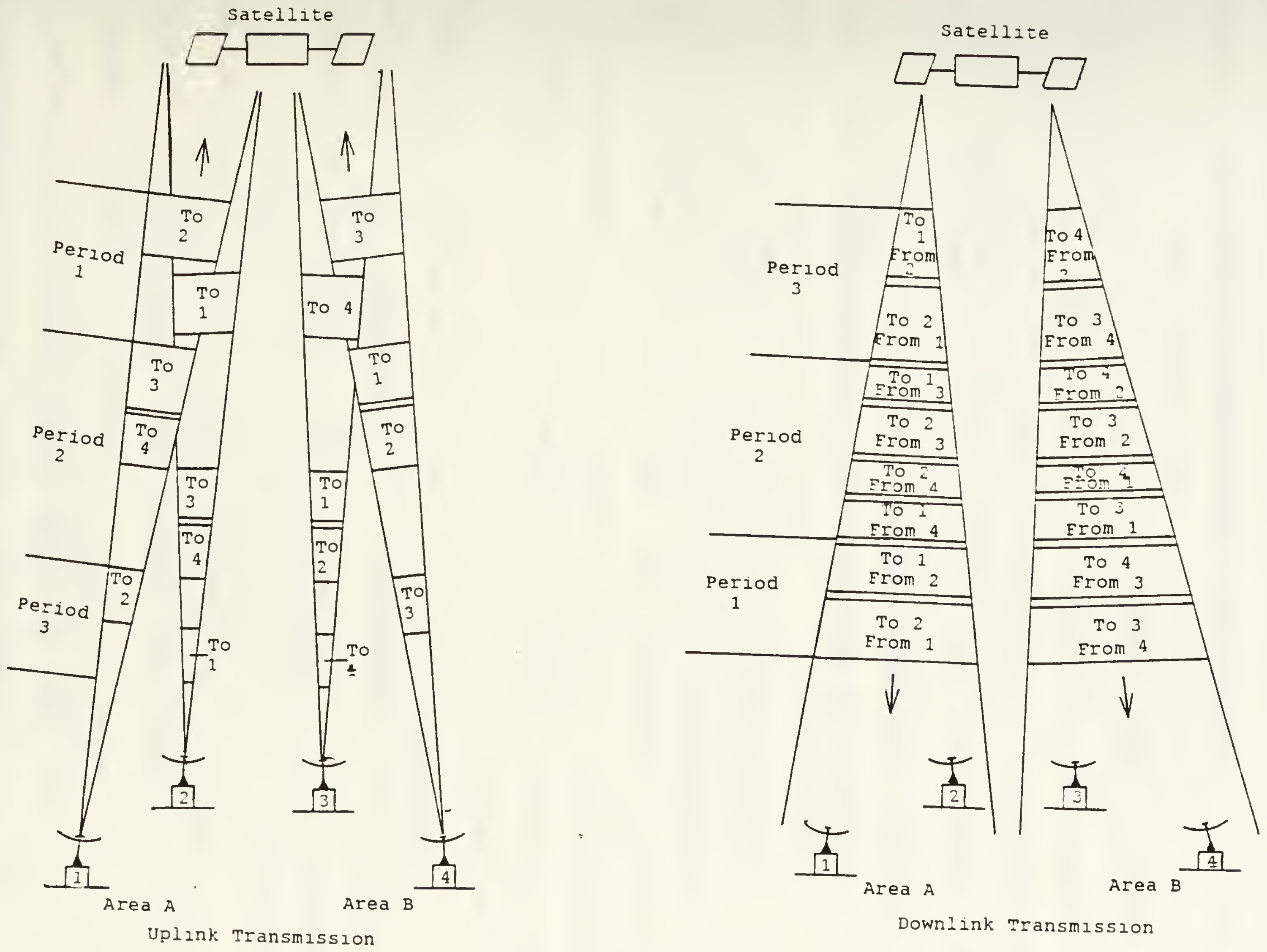

Figure 9. SS-TDMA Area-Coverage Beams

V. ANALYSIS OF THE PROPOSED DESIGNS

A. METHOD OF ANALYSIS USED

Since the objectives of the network are security, reliability and the need to get data from the outer nodes to SOC, our analysis will be based on these criteria plus cost.

B. DESIGN 1: MICROWAVE RADAR DATA LINK

1. Need to Get the Data from the Outer Nodes to SOC in a Timely Manner

In this design every site can transmit its data to SOC via intermediate nodes or directly to SOC via terrestrial microwave or satellite link. The propagation delay via the satellite link is between 250 to 300 ms. The propagation delay through terrestrial microwave link is about 6 microsecond/Km.

To measure the performance of the network, one needs to consider the average delay of the network. This delay can influence the choices made by the routing and flow control algorithms.

Delays in the computer network can be categorized as: network delays, link delays, processing delays, queuing delays, transmission delays and propagation delays. Network delay is the sum of link delays. Link delays consist of processing delays, queuing delays, transmission delays and propagation delays. Processing delay is time interval between the time the packet is correctly received at the head node of the link and the time the packet is assigned to an outgoing link plus the processing time at the data link control layer and physical layer. Queuing delay is the time interval between the time the packet is assigned to a queue for transmission and the time it starts being transmitted. Transmission delay is the time required to transmit the packet. Propagation delay is the time required for the packet to travel from the head node to the tail node of the link. In this section, the analysis is based on the propagation and transmission delays.

To determine the performance of a terrestrial link, the following formula can be used [Refs. 13 and 23]:

$$a = \frac{T_p}{T_d} \tag{4}$$

where,

- a is the ratio of the propagation delay to the transmission delay.
- T_p is the propagation delay, or T_p is the physical separation (S, in meters)/velocity of propagation V, in meters per second.
- T_d is the transmission delay, or T_d is the number of bits to be transmitted/link data rate, in bits per second.

If a<1, the round trip delay is determined by the transmission delay. If a=1, the round trip delay is determined by both the transmission and propagation delays.

If $a>1$, the round trip delay is determined by the propagation delay. [Ref. 23]

Bit errors in the transmission link must be corrected. There are two types of error control:

1) Error detection

2) Automatic repeat request (ARQ).

Error detection can be achieved by using a cyclic redundancy check (CRC). With ARQ, if an error is detected, the receiver requests the transmitter to retransmit the frame. There are three types of ARQ:

1) Stop-and-Wait ARQ

2) Go-back-N ARQ

3) Selective-repeat ARQ

Stop-and-wait ARQ is used for half-duplex transmission in which two stations alternate transmission. If this technique is used for full-duplex transmission, the throughput is low. If the link propagation delay is significantly greater than the frame length, the throughput will be low. If the propagation delay is very small (or negligible) due to a short link, then the throughput will be high. [Ref. 23]

Go-back-N ARQ is commonly used in high-level data link control (HDLC) and synchronous data link control (SDLC). With this technique, the frames are transmitted continuously, if available, without waiting for the next frame to be requested. The Go-back number N is a parameter that is used to determine the number of successive frames to be sent in the absence of a request for a new frame. In a go-back-N ARQ, sender and receiver sequence numbers N(S) and N(R) are modulo-M (where, M can be 8 or 128). In this case, N(S), N(R) = 0, 1, 2, ..., M-1 and the window size (N) is less than or equal to (M-1). [Ref. 23]

With the selective-repeat ARQ method, the receiver requests retransmission only for those frames that are in error. The receiver has a reordering buffer of size N (where, N is the window size). Sender and receiver sequence numbers N(S) and N(R) are modulo-M (where, M can be 8 or 128). In this case, N(S), N(R) = 0, 1, 2, ..., M-1 and the window size (N) is less than or equal to M/2. The maximum throughput is 1-P where P is the probability that the frame will be in error.

For Stop-and-wait ARQ (error control), the maximum throughput can be calculated as follows [Refs 13 and 23]:

$$p = \frac{1-P}{1+aP} \qquad (5)$$

where,

- p is the maximum throughput.
- P is the probability that a frame is received in error.
- a is the ratio of the propagation delay to the transmission delay.

For Go-back-N ARQ (error control), the maximum throughput can be calculated as follows [Refs. 13 and 23]:

$$p = \frac{1-P}{1+aP} \qquad (6)$$

For this formula, N>a+1.

EXAMPLE 1 [Refs. 23 and 24]: Terrestrial link with capacity of 9600 bps and the number of bits to be transmitted is 1200 bits. The distance between two stations is 1000 Km and propagation delay is 6 microsecond/Km. Assume the frame error probability is:

$$P = 1.2\text{x}10^{-2}$$

and error control is Go-back-N ARQ. Calculate the ratio of the propagation delay to the transmission delay and find the maximum throughput.

Answer: The propagation delay or P_d can be calculated as follows:

$$P_d = (1000 \text{ Km})\ 6\frac{\mu\text{sec}}{\text{Km}}$$

$$P_d = 6 \text{ msec}$$

The transmission delay is:

$$T_d = \frac{1200}{9600}$$

$$T_d = 125 \text{ msec}$$

Therefore, the total propagation time delay is:

$$T_p = 125+6$$

$$T_p = 131 \text{ msec}$$

The ratio of the propagation delay to the transmission delay is:

$$a = \frac{2T_p}{T_d}$$

$$a = \frac{262}{125}$$

$$a = 2.096$$

In this case, a is the round trip propagation plus processing delay divided by the transmission delay.

For Go-back-N ARQ, the maximum throughput is:

$$p = \frac{1-P}{1+aP}$$

$$p = \frac{1-1.2\text{x}10^{-2}}{1+2.096\text{x}1.2\text{x}10^{-2}}$$

$$p = \frac{0.988}{1.025152}$$

$$p = 0.9637595205$$

a. Traffic Estimation

The traffic flowing in the proposed design is estimated as follows [Ref. 25]:

1) Total number of users at the remote locations: 70

2) Total number of enquiries per user per day: 2

3) Number of characters per enquiry per user: 100 (to the computer)

4) Number of characters per enquiry per user: 1000 (from the computer)

5) Total number of bits per character: 10

Therefore, the daily volume of traffic V_t, to the computer can be calculated as follows:

$$V_t = 70x2x100x10$$

$$V_t = 140{,}000 \text{ bits/day}$$

The daily volume of traffic V_t, from the computer is:

$$V_t = 70x2x1000x10$$

$$Vt = 1{,}400{,}000 \text{ bits/day}$$

Thus, the total daily volume of traffic V_T is:

$$V_T = 140{,}000+1{,}400{,}000$$

$$V_T = 1{,}540{,}000 \text{ bits/day}$$

Method 1: Suppose about 20% of the daily volume of traffic occurs during the busiest hour of an 8 hour day. Therefore, the traffic during the busiest hour of day, T_b, is:

$$T_b = \left(\frac{20}{100}\right)(2,540,000)$$

$$T_b = 308,000 \text{ bits}$$

Method 2: Suppose the amount of traffic during the busiest hour of day is 2.5 times the average hourly rate of traffic for the whole day. The estimated amount of traffic during the busiest hour of an 8 hour day is:

$$T_b = (2,5)\left(\frac{1,540,000}{8}\right)$$

$$T_b = 481,250 \text{ bits}$$

b. Design 1 Propagation Time Delay Analysis

Normally, the response time for an interactive user is about 3 seconds and must never exceed 7 seconds [Ref. 25]. Response time can be defined as the time interval between an event (user enquiry) and the system's response to the event. This response time is dependent upon the network delay, such as processing delay, queuing delay, transmission delay and propagation delay.

In this design, the frequency band is 6 Ghz, the maximum channel bandwidth is 30 Mhz, giving a data rate of 90 Mbps. Assume the number of bits to be transmitted between stations is 1 million and the propagation delay is about 6 microsecond/Km. In this case, the distance is the direct link between site radars or the distance from one site to another using repeaters. The propagation delay between each link can be determined as follows:

(1) The Total Propagation Time Delay Between SOC and TKT. From Figure 5, the distance between the SOC and TKT site radars is 50 Km. Therefore, the propagation delay for this link is:

$$P_d = (50\ \mathrm{Km})\ 6\frac{\mu\mathrm{sec}}{\mathrm{Km}}$$

$$P_d = (0.3\ \mathrm{msec})$$

The transmission delay is:

$$T_d = \frac{1\mathrm{x}10^6}{90\mathrm{x}10^6}$$

$$T_d = 11.11\ \mathrm{msec}$$

Therefore, the total propagation time delay is:

$$T_p = 11.11+0.30$$

$$T_p = 11.41\ \mathrm{msec}$$

(2) The Total Propagation Time Delay Between TKT and PKB. The distance between TKT and PKB site radars is 1085 Km. The propagation delay for this link is:

$$P_d = (1085\ \mathrm{Km})\ 6\frac{\mu\mathrm{sec}}{\mathrm{Km}}$$

$$P_d = 6.51\ \mathrm{msec}$$

The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

Thus, the total propagation delay for this link is:

$$T_p = 11.11+6.51$$

$$T_p = 17.62 \text{ msec}$$

(3) The Total Propagation Time Delay Between PKB and LSW. The distance between the PKB and LSW site radars is 630 Km. The propagation delay for this link is:

$$P_d = (630 \text{ Km})\ 6\frac{\mu sec}{Km}$$

$$P_d = 3.78 \text{ msec}$$

The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay for this link is:

$$T_p = 11.11+3.78$$

$$T_p = 14.89 \text{ msec}$$

(4) The Total Propagation Time Delay Between LSW and RNI. The straight line distance between the LSW and RNI site radars is 1260 Km. These site radars will use a satellite link for communication. Assume the capacity of this satellite link is 90 Mbps and the number of bits to be transmitted is 1 million (similar to the capacity of the terrestrial link). The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The propagation delay via satellite link is 250 msec. Thus, the total propagation time delay for this link is:

$$T_p = 11.11+2.50$$

$$T_p = 261.11 \text{ msec}$$

(5) The Total Propagation Time Delay Between PKB and RNI. The straight line distance between the PKB and RNI site radars is 800 Km. This link also uses a satellite link. The propagation delay via satellite link is 250 msec. Using the same capacity, the transmission delay via this link is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 11.11+2.50$$

$$T_p = 261.11 \text{ msec}$$

(6) The Total Propagation Time Delay Between SOC and MDN. The distance between the SOC and MDN site radars is 640 Km. The propagation delay is:

$$P_d = (640 \text{ Km})\ 6\frac{\mu\text{sec}}{\text{Km}}$$

$$P_d = 3.84 \text{ msec}$$

The transmission delay is:

$$T_d = \frac{1\text{x}10^6}{90\text{x}10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 11.11+3.84$$

$$T_p = 14.95 \text{ msec}$$

(7) The Total Propagation Time Delay Between MDN and BPP. The distance between the MDN and BPP site radars is 1025 Km. Thus, the propagation delay is:

$$P_d = (1025 \text{ Km})\ 6\frac{\mu\text{sec}}{\text{Km}}$$

$$P_d = 6.15 \text{ msec}$$

The transmission delay is:

$$T_d = \frac{1\times10^6}{90\times10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 11.11+6.15$$

$$T_p = 17.26 \text{ msec}$$

(8) The Total Propagation Time Delay Between BPP and RNI. The straight line distance between the BPP and RNI site radars is 1100 Km. This link is also via satellite. The propagation delay via satellite link is 250 msec. The transmission delay of this link is:

$$T_d = \frac{1\times10^6}{90\times10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay for this link is:

$$T_p = 11.11+250$$

$$T_p = 261.11 \text{ msec}$$

(9) The Total Propagation Time Delay Between SOC and RNI. The straight line distance between the SOC and RNI site radars is 1130 Km. This link is also via satellite.

The propagation delay via satellite link is 250 msec. The transmission delay of this link is:

$$T_d = \frac{1\times10^6}{90\times10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay for this link is:

$$T_p = 11.11+250$$

$$T_p = 261.11 \text{ msec}$$

c. Route Selection

For this design, a selection of a route is based on the performance of the link, such as delay, throughput, cost and the number of hops. As shown in Figure 10, the best way to send data from the outer nodes to SOC is as follows:

1) From LSW to SOC: the data is sent via nodes PKB and TKT. The total propagation time delay via these nodes is 14.89+17.62+11.41 = 43.92 msec.

2) From RNI to SOC: the data is sent via satellite direct to SOC. The total propagation time delay is 11.11+250 = 261.11 msec.

3) From PKB to SOC: the data is sent via node TKT. The total propagation time delay via this node is 17.62+11.41 = 29.03 msec.

4) From TKT to SOC: the data is sent directly to SOC via terrestrial link. The total propagation time delay for this link is 11.41 msec.

5) From MDN to SOC: the data is sent directly to SOC via terrestrial link. The total propagation time delay for this link is 14.95 msec.

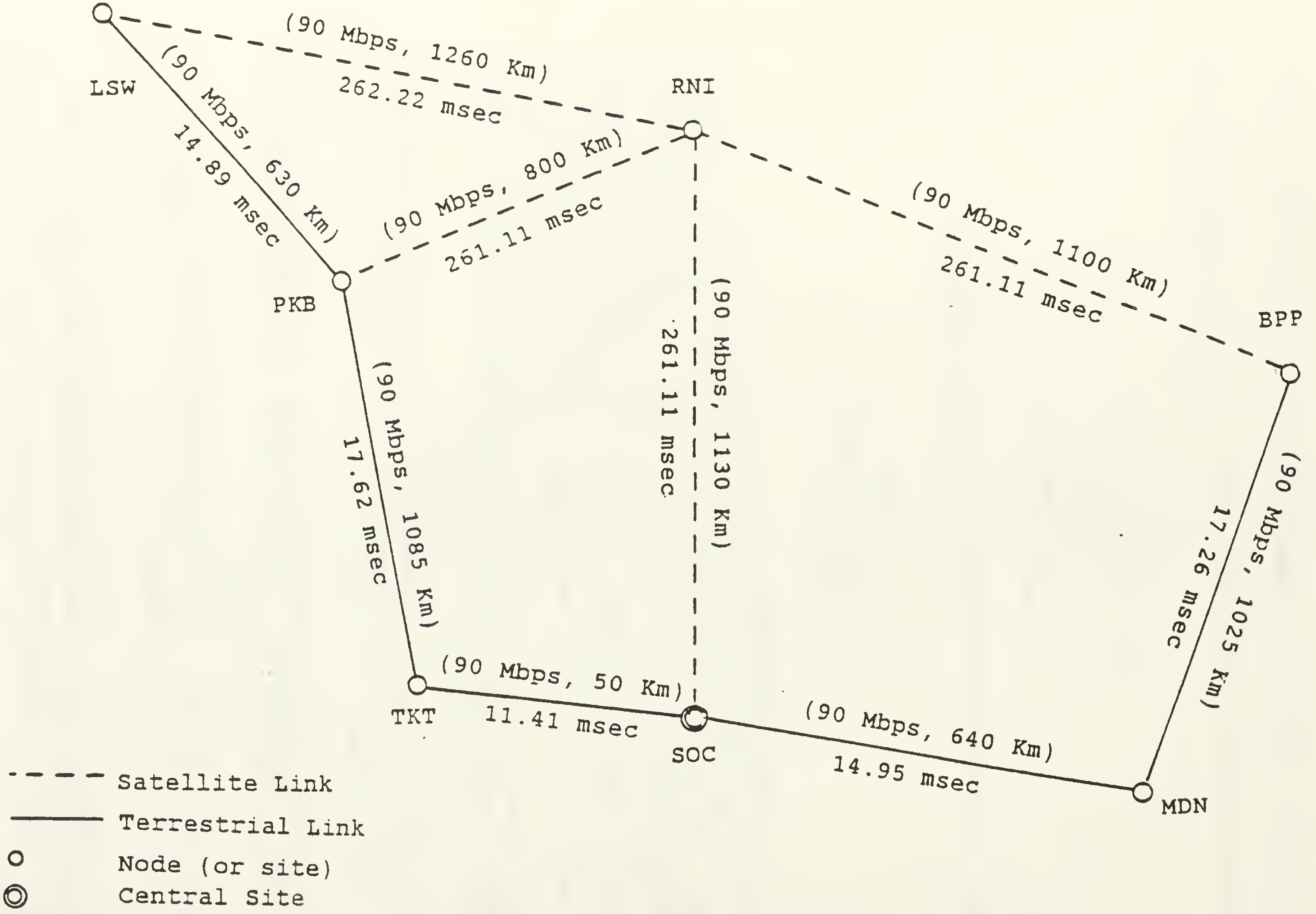

Figure 10. Design 1: Total Propagation Time Delay

6) From BPP to SOC: the data is sent via node MDN. The total propagation time delay for this link is 17.26+14.95 = 32.21 msec.

d. **File Transfer Protocol (FTP)**

File Transfer Protocol (FTP) can be used to send data and commands from SOC to the RSRs, from the RSRs to SOC and to transfer data between RSRs. If a user in site A wishes to access a file in site B, this user must establish a FTP connection to site B. After the connection has been established, three possibilities can occur: 1) a file from site B can be transferred to site A, 2) a file from site A can be sent to site B, and 3) data exchange can be made between site A and site B via site C (a third party transfer). To do this, the FTP must have the following items [Ref. 13]:

1) a user interface for accepting requests
2) the ability to communicate with other FTPs
3) the ability to get a file

2. **Security**

Since most of the links are within the Indonesian territory, the security of the links can be established according to the missions of the Indonesian Air Force. However, special attention should be paid to the satellite link, because transmission via satellite systems can be received by many earth stations and many earth stations can transmit data to satellite systems. To increase security end-to-end data encryption should be done. By doing this the data remains encrypted while it is flowing through the links. End-to-end data encryption has been used successfully in the Advanced Research Projects Agency Network (ARPANET) of the U._S. Department of Defense. In this system, every link is encrypted. Encryption is a method of converting a data stream into an encoded data stream by using a 'key' (encryption algorithm). The receiver uses the same key to decode the message. There are two types of data communication encryption: end-to-end and link. End-to-end data encryption encodes a message at the source and decodes the message at destination only. Link encryption encodes and decodes a message in every node between the source and destination. End-to-end data encryption is more secure than link encryption, because the data cannot be decoded before it reaches the destination. For a more secure system, the two encryption methods can be combined. To make the message unbreakable, there is a need to use a sufficiently complex key and sufficiently complex algorithms. Other methods of cryptography can also be used to protect the links from disasters and intruders. [Ref. 26]

3. Reliability

The reliability of the first design is good. If the satellite link fails, communication will only be lost between those sites which rely on the satellite. The sites affected by the failure will still be able to communicate with the other sites by using the backup system, such as radio link, telephone line and terrestrial microwave link. Other sites which are not using the satellite link will still be able to use the terrestrial microwave links.

4. Economic Trade-offs

The cost of the communication system via the terrestrial microwave link is dependent upon the distance between sites, while the cost of the satellite microwave link is independent of this distance. If the cost of communication via terrestrial microwave exceeds the cost of the satellite microwave system, it is better to use the satellite microwave link. On the other hand, if the cost of the satellite microwave link exceeds the cost of the terrestrial microwave link, it is better to use the terrestrial microwave link. Therefore, there are trade-offs between these two media.

C. DESIGN 1: FULLY CONNECTED SATELLITE LINK

1. Need to get the Data from the Outer Nodes to SOC in a Timely Manner

In this design, the satellite system can be used to collect data from every site and then retransmit the data to SOC. This type of communication is called multipoint-to-point communication. The SOC must be able to send command and control back to every site radar.

EXAMPLE 2: Satellite link has a capacity of 56 Kbps and a propagation delay of 250 msec. Suppose the number of bits to be transmitted is 1200 and the probability that a frame is received in error is:

$$P = 1.2x10^{-2}$$

Calculate the ratio of the propagation delay to the transmission delay and find the maximum throughput by using Go-back-N ARQ error control.

Answer: The propagation delay via satellite link is 250 msec. The transmission delay can be calculated as follows:

$$T_d = \frac{1200}{56000}$$

$$T_d = 21.4 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+21.4$$

$$T_p = 271.4 \text{ msec}$$

The ratio of the propagation delay to the transmission delay is:

$$a = \frac{2T_p}{T_d}$$

$$a = \frac{542.8}{21.4}$$

$$a = 25.4$$

In this case, a is the round trip propagation plus processing delay divided by the transmission delay.

Therefore a+1 = 26.4, and N = 127(or M = 128) must be used. In this case, N>(a+1).

So, the maximum throughput is:

$$p = \frac{1-1.2x10^{-2}}{1+25.4x\ .2x10^{-2}}$$

$$p = \frac{0.988}{1.3048}$$

$$p = 0.7572041692$$

a. **Design 2: Propagation Time Delay Analysis**

One of the objectives of this work is to get the data from the outer nodes to SOC in a timely manner. For this design, the analysis will be based on the propagation delay and transmission delay from the outer nodes via the satellite system to SOC. This technique is illustrated in Figure 11.

In this design, the frequency band is 6 Ghz, the maximum channel bandwidth is 30 Mhz, giving a data rate of 90 Mbps. The propagation delay via satellite link is 250 msec. Assume the number of bits to be transmitted is 1 million and the probability that a frame is received in error is:

$$P = 1.2x10^{-2}$$

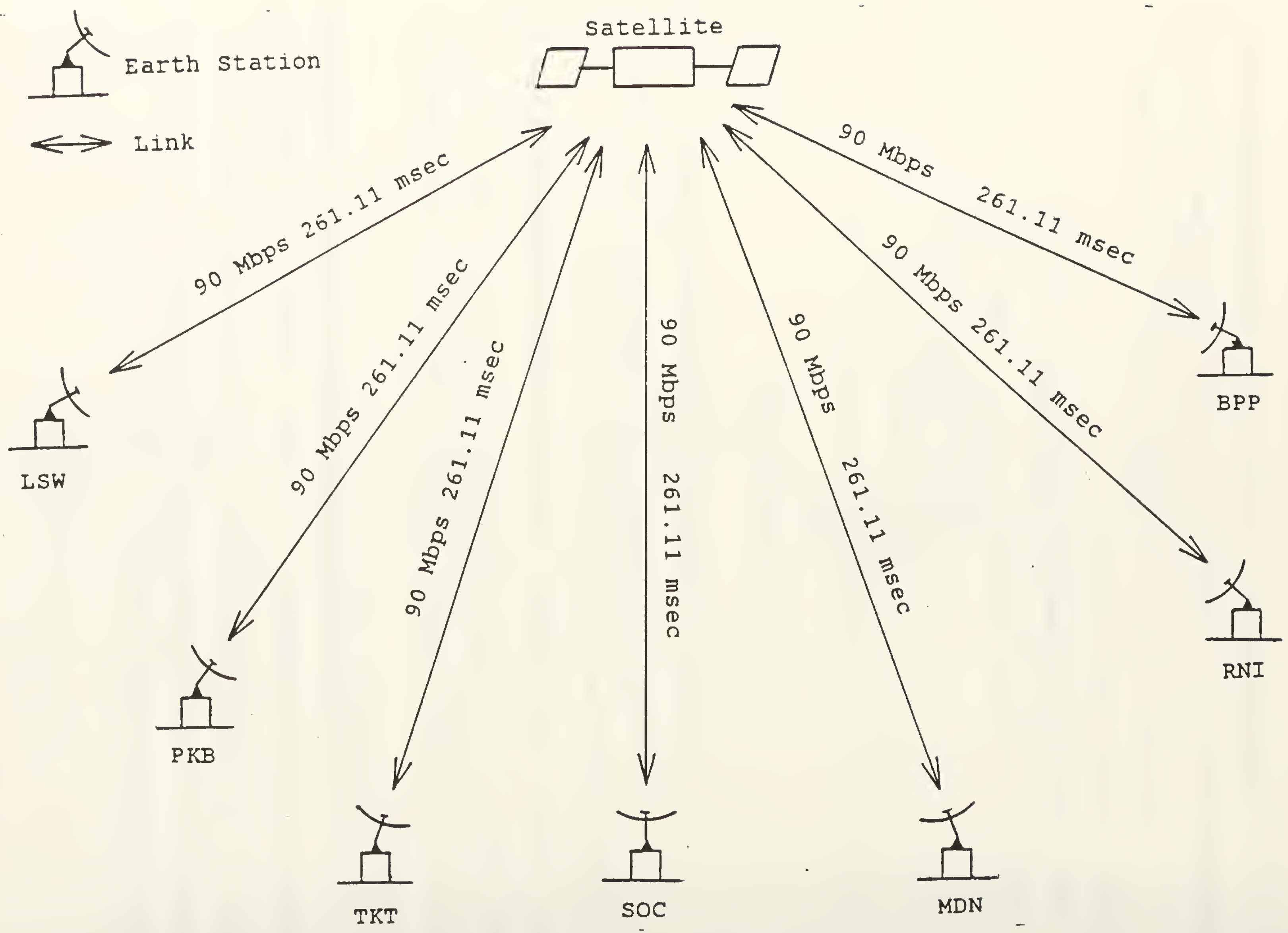

Figure 11. Design 2: Total Propagation Time Delay

The propagation delay between each link can be determined as follows:

(1) The Total Propagation Time Delay Between LSW and SOC. The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+11.11$$

$$T_p = 261.11 \text{ msec}$$

(2) The Total Propagation Time Delay Between RNI and SOC. The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+11.11$$

$$T_p = 261.11 \text{ msec}$$

(3) The Total Propagation Time Delay Between PKB and SOC. The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+11.11$$

$$T_p = 261.11 \text{ msec}$$

(4) The Total Propagation Time Delay Between BPP and SOC. The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+11.11$$

$$T_p = 261.11 \text{ msec}$$

(5) The Total Propagation Time Delay Between MDN and SOC. The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+11.11$$

$$T_p = 261.11 \text{ msec}$$

(6) The Total Propagation Time Delay Between TKT and SOC. The transmission delay is:

$$T_d = \frac{1x10^6}{90x10^6}$$

$$T_d = 11.11 \text{ msec}$$

The total propagation time delay is:

$$T_p = 250+11.11$$

$$T_p = 261.11 \text{ msec}$$

b. Route Selection

For this design, the satellite system uses SS-TDMA. For this point-to-point link, there are separate beams from the satellite for the various receiving stations (See Figure 8). Each site can send its data directly to SOC via the satellite link. To send data from TKT to SOC, it is better to use terrestrial microwave relay because the distance is only about 50 Km. The propagation delay via satellite link is significantly greater than the terrestrial propagation delay for this case. However, in a wartime situation the combination of both should be used.

2. Security

The security of this link varies from poor to good. The signals from satellite system can be received by many earth stations and many earth stations can transmit to the satellite system. The best way to protect the link from intruders is by using some form of data encryption.

Uplink and downlink communication via the satellite system can be jammed by the enemy. This can be done by positioning their satellite in the region of the satellite to be jammed. This type of jamming can be overcome by using a frequency-hopping method and spread spectrum modulation. Frequency-hopping is used to make a signal hop from one frequency to another frequency. This frequency hop causes the jammer to spread the jamming signal across the entire bandwidth. Spread spectrum modulation is an anti-jamming technique in which the data modulated signal is transmitted in a bandwidth that is greater than the frequency content of the original data. Therefore, the jammer will not know whether his jamming is effective or not. [Ref. 19]

3. Reliability

The reliability of this link is not as good, because it takes the form of a star topology. If the satellite system fails, the network operation completely stops. If one satellite system is destroyed by an enemy, a standby satellite system should be available to take over the function of the failed system. The reliability of the satellite system depends on the reliability of its individual components. If one component fails, it cannot be repaired. So, there is a need to replicate the components of the satellite system. It must be easy to switch to a standby component. Each individual component of the satellite system must be highly reliable and tested before it is put into space. [Ref. 3]

The Indonesian Air Force should not rely exclusively on satellite links. Other methods of communication should be available in case of satellite failure.

4. Economic Trade-Offs

Transmission cost via satellite link is independent of distance. The central site can be placed anywhere within the satellite coverage. For satellite communication systems, there is a need to consider space station and earth station costs. On orbit cost is about $40 million or less and the annual cost per circuit is about $80 or less. However, advances in communication satellite technology will probably make the cost of satellite channels decrease. As the satellite system becomes more powerful, the cost of the earth station will decrease. [Ref. 2]

VI. CONCLUSIONS

Design 1 is more secure and more reliable than Design 2 because this design uses terrestrial microwave relay and most of the links are inside Indonesian territory. Design 2 is based entirely on the satellite relay. If the satellite system fails, then the operation of the network completely stops. Also, transmission via satellite system can be received by many earth stations and many earth stations can transmit to the satellite system.

For these reasons, in a wartime situation it would be better to use Design 1 and use Design 2 as a backup system.

A survey is very important before the actual terrestrial links are established. A survey is needed to check the man-made obstacles and to see the actual situation, such as big trees which are not shown on the map. The proposed terrestrial links must be checked against the current topographical maps and aeronautical charts in order to be able to know the elevation and contour lines and also to prevent interference with other antennas. Therefore, a survey should be done before the actual links are established.

SOC should be replicated because it might be destroyed by bombs, fire, etc. If one central site fails, the other central site can take over the function of the failure system. Therefore, the second central site should be planned and protected from bombs, fire, etc., in order to be able to take over the function of the failed system.

In a wartime situation, the combination of the Design 1 and Design 2 should be used in order to increase security and reliability of the RSRs communication systems.

This system could be expanded so the Indonesian Air Force could cover all of the Indonesian air territory.

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